Acoustic Characterization of Mesoscale Objects

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Mesoscale is an emerging area of science and engineering that focuses on the study of materials with dimensions, features, and structures that range from a few millimeters down to a few micrometers. Mesoscale objects typically have embedded features that require resolutions on the order of a few micrometers. Mesoscale nondestructive characterization technologies are required that can, first, penetrate into or through a few millimeters of diverse materials and, second, provide spatial resolutions of about a micrometer.

An acoustic technique is attractive because it offers high sensitivity to features such as thickness and interface quality that are important to mesoscale objects. In addition to the resolution requirements, many mesoscale objects require a noncontact technique to avoid damaging fragile surfaces.

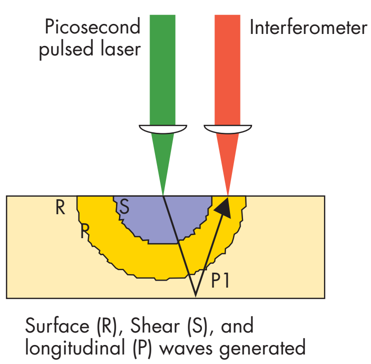

Figure 1. Schematic of Laser UT. Laser UT uses a pulsed laser as a source to generate acoustic waves, and a laser interferometer to detect them. The source and receiver can be on the same side (as shown) or on opposite sides of the object. The acoustic wave travels through the object before it is detected. Use of a pulsed laser gives temporal resolution to the detected signal.

Project Goals

The goal of this project is to research characterization of mesoscale objects using noncontact laser ultrasonic (UT) techniques (Fig. 1). Spatial resolution requirements in mesoscale objects require the use of frequencies from 100 MHz to 10 GHz to acoustically characterize features from 5 to 0.5 μm in size. At this time, laser UT in this frequency range does not exist (Fig. 2).

The three phases of this project are viability (FY2004), prototype (FY2005-FY2006) and demonstration (FY2006). The biggest challenge to this research, addressed in the viability phase, is the propagation distance attainable at GHz frequencies. Mesoscale objects usually have structures with thicknesses on the order of 25 to 200 μm. Inspection of these structures requires propagation distances of the same order. Propagation distance is governed by attenuation of the acoustic wave and is strongly dependent upon material.

Another challenge to this work is the identification of optimal laser parameters to mitigate ablative damage to the object upon acoustic wave generation.

Relevance to LLNL Mission

This proposal impacts the DNT, NIF, Engineering, and Chemistry and Materials Science Directorates through high-energy-density physics laser target fabrication and characterization. Other applications, such as fuel cells, biological cells, and tissue research, will benefit the Nonproliferation, Arms Control and International Security, and the Biology and Biotechnology Research Directorates.

FY2004 Accomplishments and Results

In FY2004, the viability of using GHz ultrasound in materials important to the Laboratory was demonstrated using a laser-based acoustic system at frequencies ranging from 500 MHz to 1 GHz. From these measurements, acoustic velocity and attenuation at 800 MHz are derived for some materials (see table). Also listed in the table are ablative and thermoelastic propagation distances. These propagation distances generally exceed the 200-μm nominal thickness of mesoscale objects. These results indicate that GHz laser UT is viable for characterization of mesoscale objects. Establishment of viability sets the stage for the design and construction of an acoustic characterization system for mesoscale materials.

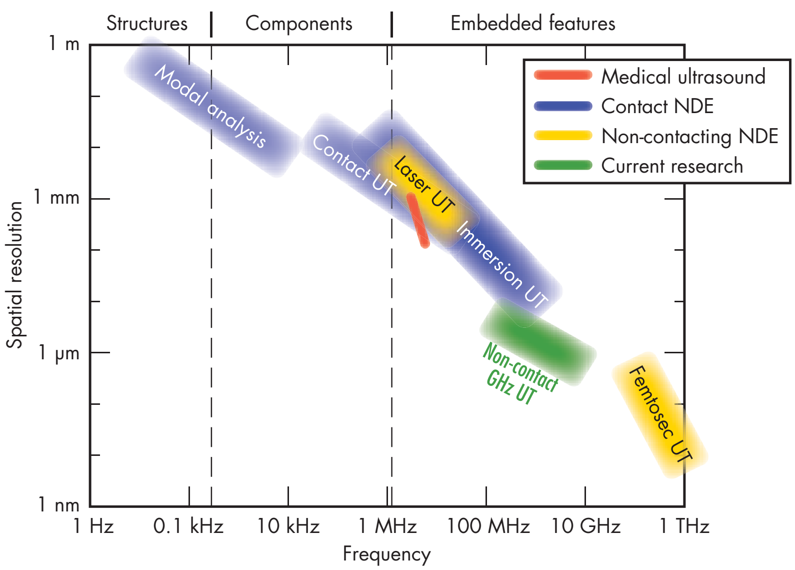

Figure 2. Chart showing two key parameters describing acoustic characterization: which systems exist, and the range of the particular technique.

Material	Approx. ablation energy (µJ)	Attenuation @ 0.8 GHz (dB/mm)	Wave speed (mm/µs)	Wavelength @ 0.8 GHz (µm)	Prop. distance, thermoelastic (µm)	Prop. distance, ablative (µm)
Aluminum	0.13	49.9	6.58	8.2	700	1100
Copper	0.14	77.8	4.07	5.1	225	525
Vanadium	0.13	52.3	5.88	7.4	225	825
Gold	0.16	58.6	3.25	4.1	200	250
Tantalum	0.15	69.6	4.26	5.3	100	200
Polystyrene	0.2*	68.7	2.05	2.6	350	—
Polycarbonate	0.2*	40.1	1.95	2.4	525	—
Polyamide	0.2*	60.5	1.89	2.4	150	—

*thermoelastic excitation only

Measured laser and acoustic parameters from the laser UT system, demonstrating the viability of GHz acoustics.

Related References

1. Chambers, D., D. Chinn, and R. Huber, "Optical Mapping of the Acoustic Output of a Focused Transducer," *Proceedings of the 147th Acoustical Society of America Meeting*, 2004.

2. Scruby, C., Laser Ultrasonics: Techniques And Applications, Adam Hilger, New York, New York, 1990.

FY2005 Proposed Work

In the FY2005 prototype phase, acoustic parameters measured in the viability phase will be used to model GHz laser UT. With this optoacoustic model we will determine resolution and penetration capability of GHz ultrasound in other materials; design the GHz acoustic system; study the onset of ablation and its effects on wave generation; and model the characterization of mesoscale objects.

Designs for the acoustic characterization system will be finalized, and construction of the system will begin. Testing of the system is scheduled to take place during the second half of FY2005. Extensive modeling of laser/material interaction will be undertaken to assist with modeling of the acoustic waves that are generated and then propagate through the material.